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The Mars Reconnaissance Orbiter Mission Plan

Robert E. Lock*, Peter Xayprasẹuth†, M. Daniel Johnston*, C. Allen Halsell*,
Angela L. Bowes†, Daniel T. Lyons*, T. You*, Dolan E. Highsmith†, Moriba Jah†

Jet Propulsion Laboratory, California Institute of Technology
Pasadena, California

This paper describes the Mars Reconnaissance Orbiter Mission Plan with emphasis on major mission activities and key challenges in mission design, spacecraft design, and science data acquisition. An overview of the mission will be provided which includes: the mission objectives, a description of the orbiter and its payloads, and the basic concept of operations. Also included will be a description of the science orbit at Mars and mission data return strategies.

INTRODUCTION

Figure 1. MRO Spacecraft

In August 2005, NASA will launch the Mars Reconnaissance Orbiter (MRO). This mission has the primary objective of placing a science orbiter into Mars orbit to perform remote sensing investigations that will characterize the surface, subsurface and atmosphere of the planet and will identify potential landing sites for future missions. A major mission of the Mars Exploration Program (MEP), MRO will pursue the Program's "Follow-the-Water" theme by conducting science observations that will return sets of globally distributed data that will be used to: 1) advance our understanding of the current Mars climate, the processes that have formed and modified the surface of the planet, and the extent to which water has played a role in surface processes; 2) identify sites of possible aqueous activity indicating environments that may have been or are conducive to biological activity; and 3) identify and characterize sites for future landed missions. Figure 1 shows an artists conception of the MRO orbiter in Mars orbit.

In addition to its scientific objectives, MRO will provide telecommunications relay capability for follow-on missions and will conduct telecom and navigation demonstrations in support of future MEP activities.

* Senior Member of Engineering Staff
† Member of Engineering Staff

MISSION OBJECTIVES

The Mars Reconnaissance Orbiter (MRO) mission has the primary objective of placing a science orbiter into Mars orbit to perform remote sensing investigations that will characterize the surface, subsurface and atmosphere of the planet and will identify potential landing sites for future missions. The MRO payload will conduct observations in many parts of the electromagnetic spectrum, including ultraviolet and visible imaging, visible to near-infrared imaging spectrometry, thermal infrared atmospheric profiling, and radar subsurface sounding, at spatial resolutions substantially better than any preceding Mars orbiter. In pursuit of its science objectives, the MRO mission will:

- Characterize Mars' seasonal cycles and diurnal variations of water, dust, and carbon dioxide.
- Characterize Mars' global atmospheric structure, transport and surface changes.
- Search sites for evidence of aqueous and/or hydrothermal activity.
- Observe and characterize the detailed stratigraphy, geologic structure, and composition of Mars surface features.
- Probe the near-surface Martian crust to detect subsurface structure, including layering and potential reservoirs of water and/or water ice.
- Characterize the Martian gravity field in greater detail than previous Mars missions to improve knowledge of the Martian lithosphere and potentially of atmospheric mass variation.
- Identify and characterize numerous globally distributed landing sites with a high potential for scientific discovery by future missions.

In addition, MRO will provide critical telecommunications relay capability for follow-on missions and will conduct, on a non-interference basis with the primary mission science, telecom and navigation demonstrations in support of future MEP activities. Specifically, the MRO mission will:

- Provide navigation and data relay support services to future MEP missions
- Demonstrate Optical Navigation techniques for precision delivery of future landed missions.
- Perform an operational demonstration of high data rate Ka-band telecommunications and navigation services

Designed to operate after launch for at least 5.4 years, the MRO orbiter will use a new spacecraft bus design provided by Lockheed Martin Space and Strategic Missiles in Denver, Colorado. The orbiter payload will consist of six science instruments and three new engineering payload elements listed as follows:

Science Instruments

- HiRISE, High Resolution Imaging Science Experiment
- CRISM, Compact Reconnaissance Imaging Spectrometer for Mars
- MCS, Mars Climate Sounder
- MARCI, Mars Color Imager
- CTX, Context Camera
- SHARAD, Shallow (Subsurface) Radar

Engineering Payloads

- Electra UHF communications and navigation package
- Optical Navigation (Camera) Experiment
- Ka Band Telecommunication Experiment

To fulfill the mission science goals, eight scientific investigations teams have been selected by NASA. MARCI, MCS, HiRISE, and CRISM are led by Principal Investigators (PI). The MARCI PI and Science Team also act to provide and operate, as Team Leader (TL) and Team Members, the CTX facility instrument. The Italian Space Agency (ASI) will provide a second facility instrument, SHARAD, for flight on MRO. ASI and NASA have both selected members of the SHARAD investigation team. In addition to the instrument investigations, Gravity Science and Atmospheric Structure Facility Investigation Teams will use data from the spacecraft telecommunications and accelerometers, respectively, to conduct scientific investigations. The individual science instrument capabilities that must be met to achieve mission success are shown in table 2.1, together with key instrument attributes and observing modes.

Table 1
INVESTIGATION SCIENCE OBJECTIVES

Investigation	*Instrument Type*	*Measurement Objectives (Estimated Capabilities)*	*Science Goals*	*Attributes*
CRISM	High-Resolution Imaging Spectrometer	Hyper-spectral Image Cubes 570 spectral bands, 0.4-4.05 micrometers *From 300 km:* 18 m/pixel with 11 km swath	Regional & Local Surface Composition and Morphology	• Moderately High Spectral & Spatial Resolution • Targeted & Regional Survey • Very High Data Rate
CTX	Mono-chromatic Context Camera	Panchromatic (minus blue) Images *From 300 km altitude:* 30 km swath & 6m/pixel *Context Imaging for HiRISE/CRISM & MRO Science*	Regional Stratigraphy and Morphology	• Moderately High Resolution with Coverage • Targeted & Regional Survey • High Data Rate
HiRISE	High Resolution Camera	Color Images, Stereo by Site Revisit *From 300 km:* < 1 m/pixel (Ground sampling @ 0.3 m/pixel) *Swath*: 6 km in RED (broadband) 1.2 km in Blue-Green & NIR	Stratigraphy, Geologic Processes and Morphology	• Very High Resolution • Targeted Imaging • Very High Data Rate
MARCI	Wide-Angle Color Imager	Coverage of Atmospheric clouds, hazes & ozone and surface albedo in 7 color bands (0.28-0.8 μm)	Global Weather and Surface Change	• Daily Global Coverage • Daily Global Mapping • Continuous Dayside Operations • Moderate Data Rate
MCS	Atmospheric Sounder	Atmospheric Profiles of Temperature, Water, Dust, & Ices Polar Radiation Balance 0-80 km vertical coverage Vertical Resolution ~ 5 km	Atmospheric Structure, Transport and Polar Processes	• Global Limb Sounding • Daily Global Limb & On-Planet Mapping • Continuous Day/Night • Low-Data Rate
SHARAD	Shallow Subsurface RADAR	Ground Penetrating RADAR Transmit Split Band at 20MHz < 1 km; 10-20 m Vertical 1 km x 5 km Horizontal Resolution	Regional Near-Surface Ground Structure	• Shallow Sounding • Regional Profiling • High Data Rate
Gravity	S/C Telecom	S/C Range and Rate X-band 2-way Doppler / Range	Gravity Field, Mass Distribution	• Higher Resolution • Seasonal Mass Redistribution
Atmospheric Structure	S/C Accelerometers	Density and Scale Height from S/C acceleration	Upper Atmos. Structure and Circulation	• Aerobraking Phase

CRISM:	PI, Scott Murchie, Johns Hopkins University Applied Physics Lab (JHUAPL)
CTX:	TL, Michael Malin, Malin Space Science Systems (MSSS)
HiRISE:	PI, Alfred McEwen, University of Arizona
MARCI:	PI, Michael Malin, Malin Space Science Systems (MSSS)
MCS:	PI, Daniel J. McCleese, Jet Propulsion Lab (JPL)
SHARAD:	TL/PI, Roberto Seu, University of Rome, Italy; DTL, Roger Phillips, Washington University, USA
Gravity:	TL, Maria Zuber, MIT
Atmospheric Structure:	TL, Gerald Keating, George Washington University at 0NASA LaRC

MISSION DESCRIPTION

The Mars Reconnaissance Orbiter Mission is divided in time into six phases: Launch, Cruise, Approach and Orbit Insertion, Aerobraking, Primary Science, and Relay. Each phase name characterizes the principal activity that is occurring during that time period in the mission.

The MRO orbiter will be launched, from Cape Canaveral, Florida, using a Lockheed Martin Atlas V-401 launch vehicle in August 2005. The launch period is three weeks in duration.

The transit time to Mars will be approximately seven months. During this period, a series of trajectory course corrections will be carried out. The orbiter payload will be checked out and a series of instrument and spacecraft calibrations performed. The Optical Navigation Experiment, which uses images of Mars' moons to verify spacecraft position, will be conducted on approach to Mars to demonstrate the technology for future Mars missions. After arriving at Mars in March 2006, the MRO orbiter will be propulsively inserted into a highly elliptical capture orbit with a period of 35 hours. The orbiter will use aerobraking techniques to reduce its orbit to near that needed for science observations.

Once the orbit apoapsis altitude is reduced to 450 km, the orbiter will terminate aerobraking by raising periapsis to a safe altitude and begin a transition to the Primary Science Phase. A series of propulsive maneuvers will be performed over a 10 day span to establish the primary science orbit (PSO). The SHARAD antenna and the CRISM cover will be deployed, the instruments will be checked out, test observations will be collected, and any remaining calibrations will be performed. Orbiter activities in preparation for science will be temporarily suspended during a four week period surrounding solar conjunction.

The primary science phase of the mission will begin after solar conjunction and after turn-on and checkout of the science instruments in the Primary Science Orbit. The phase will start in November 2006, will extend for at least one Mars Year and will conclude prior the next solar conjunction near the end of 2008. The 255 x 320 km PSO will be a near-polar orbit with periapsis frozen over the South Pole and will be sun-synchronous with an ascending node orientation that provides a Local Mean Solar Time (LMST) of 3:00 pm at the equator. Because of the eccentricity of the Mars orbit around the Sun, true solar time will vary by nearly ± 45 minutes over the course of one Mars year.

NASA may approve,.as resources and on-orbit capability permit, continuation of science observations beyond the Primary Science Phase until end of the Relay Phase (also End of Mission). The orbiter will remain in the Primary Science Orbit during the Relay Phase.

MRO will provide critical relay support to missions launched as part of the Mars Exploration Program after MRO. For spacecraft launched in the 2007 opportunity, this relay support is likely to occur before the end of the MRO Primary Science Phase. During the Relay Phase, MRO will continue to provide critical relay support for Mars missions until its end of mission on December 31, 2010.

While all of the missions that MRO will support have not yet been selected, Phoenix, the first of the Mars Program's Scout missions has been selected to launch in the 2007 Mars opportunity. Phoenix, a lander mission that will collect and analyze soil samples, will arrive in late May 2008. MRO support for the Phoenix mission will include science imaging support for site characterization and selection and relay support for its Entry Descent and Landing activities and for its science data return. Another mission, the Mars Science Laboratory (MSL) is proposed for the 2009 Mars opportunity. MSL will also need science imaging support for site characterization and selection and relay support for EDL and science data return.

The orbiter has been designed to carry enough propellant to remain operational for 5 years beyond the end-of-mission (EOM) to support future MEP missions. No activities have been planned for this time period. To ensure that the orbiter remains in a viable orbit during this time, its orbit altitude will be increased at EOM to about 20 km inside the orbit of the Mars Global Surveyor spacecraft.

The MRO approach to planetary protection differs from any previous Mars orbiter. The NASA requirements for planetary protection allow a class III mission, like MRO, to use either the "probability of impact/orbit lifetime" or a "total bio burden" approach. MRO requires low orbits whose lifetimes are incompatible with a "probability of impact/orbit lifetime" approach to Planetary Protection. Therefore, MRO is using the "total bio burden" approach. The MRO launch targets will be biased away from a direct intercept course with Mars to ensure a less than 1 in 10,000 chance of the launch vehicle upper stage entering Mars atmosphere.

SYSTEM DESCRIPTION

The MRO orbiter consists of two major components, the spacecraft bus and the payload. The total MRO injected mass on the Atlas V 401 is 2180 kg. Of this 2180 kg, the allowable dry mass is 1031 kg; the rest of the injected mass is for needed fuel. The total dry mass supports a payload capability of 139 kg. The propulsion system can deliver a total DV capability of at least 1545 m/s. The majority of that DV capability is for use to capture at Mars.

Spacecraft Bus

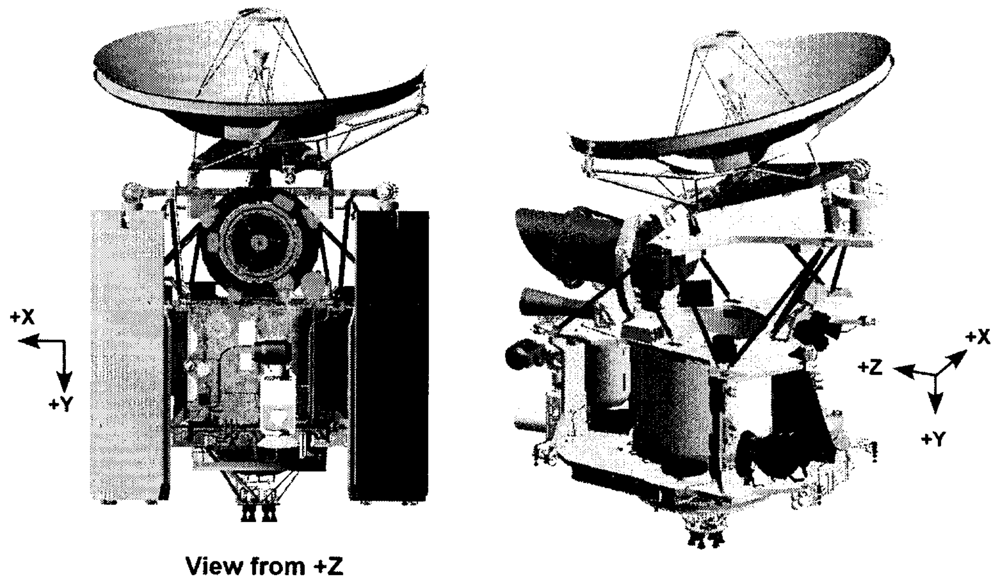

Figure 2 Obiter Overview

Solar array and high gain antenna deployments occur shortly after launch to avoid long term deep space exposure. To ensure safe capture at Mars, the propulsion system is fault tolerant to a single main engine out and a short duration computer reset event. To avoid the hazards and risks of a bipropellant propulsion system, MRO utilizes a monopropellant hydrazine design. Designed to aerobrake, the spacecraft is aerodynamically balanced to quickly "right itself" in the event of a large attitude excursion when it encounters the Martian atmosphere. The use of aerobraking reduces the total DV requirements of the mission by 1200 m/s. An overview of the Orbiter configuration is shown in figure 2.

The telecommunications subsystem will be used for receiving commands and radiometric data and for transmitting radiometric data, science data, and engineering data back to the Earth. The antenna system on the orbiter consists of a 3-meter high-gain antenna (HGA) and two low-gain antennas (LGA). The HGA will serve as the primary means of communication to and from the orbiter. The purpose of the LGAs is to ensure a reliable telecom link via a low data rate from every orbiter attitude. There are three Traveling

Wave Tube Assemblies (TWTA). Two redundant X-band TWTAs radiate RF signals at 100 watts and the Ka-band TWTA radiates at 35 watts. The small deep space transponder (SDST) is used to modulate and demodulate the RF signals for both X-band and Ka-band and uses two modulation schemes, QPSK and BPSK. The SDST can use uplink signals for coherent 2-way operations, an Ultra-stable Oscillator (USO), or its own built-in auxiliary oscillator (AUX/OS) for one-way operations. The SDST will also produce delta-DOR tones, to be used for navigation at both X-band and Ka-band.

The propulsion subsystem will be used to provide attitude control for the spacecraft, perform major propulsive maneuvers such as trajectory correction maneuvers (TCM) and Mars orbit insertion (MOI). This propulsion subsystem is pressure regulated during MOI and operates in a blow-down mode for all other mission phases. The propellant tank is sized to accommodate 1220 kg of monopropellant hydrazine. For translational control of the spacecraft, there are 12 thrusters: six MR-107N thrusters and six MR-106E thrusters. The MR-107N main engines, each producing 170 Newtons of thrust, will be used to perform the MOI burn. By using six smaller thrusters, rather than a single large main engine, the spacecraft is less susceptible to mission loss due to an engine-out failure. The MR-106E thrusters, each producing 22 Newtons of thrust, will be used to perform the smaller TCMs, and to provide thrust vector control during the MOI burn. Eight MR-103D thrusters, each producing 0.9 Newtons of thrust, will be used to provide normal attitude control (when not using RWAs) and provide roll control during MOI and TCMs.

The Command and Data Handling (C&DH) subsystem will be used to manage all forms of data on the spacecraft. Two key features of the C&DH are the Space Flight Computer and the Solid State Recorder (SSR). The Space Flight Computer is a X2000 RAD 750. that provides up to 46 MIPS (Millions of Instructions Per Second) for use by the the spacecraft subsystems, and the science and engineering instruments. There are two Gbits of DRAM available to the Space Flight Computer. The 160 Gigabit SSR is used for storage of raw instrument data and for processed telemetry frames. Once the data is in the raw data storage partition in the SSR, it will be edited and formatted by the flight computer. The formatted (packetized and framed) data will be placed back on the SSR to wait for the next downlink opportunity.

The Guidance, Navigation, and Control (GNC) subsystem relies on star trackers, sun sensors, and an Inertial Measurement Unit (IMU) to determine its attitude, and on reaction wheels and the reaction control system thrusters to maintain the orientation of the orbiter, and on an on-board ephemeris for targeting of specific sites on the surface. The reaction wheel assembly, RWA, consists of three wheels mounted perpendicularly to one another, with a fourth wheel, for redundancy, mounted in a skewed direction. The reaction wheels are used to orient the orbiter during all mission phases. The reaction control system, RCS, uses coupled thrusters to maintain the orbiter attitude and to remove the angular momentum built up by the reaction wheels.

The Electrical Power Distribution subsystem includes two solar panels and two Nickel-Hydrogen batteries. The solar panels are mounted on opposite sides of the orbiter and are capable of two-axis articulation for continuous Sun tracking in Mars orbit. Each panel has an area of approximately 10 square meters and has a power output of approximately 2000 watts at Mars at the start of the science phase. During periods of eclipse or when the orbiter turns away from the sun, energy will be provided by two 50 Amp-hours Nickel-Hydrogen batteries.

Payload Description

During its two-year primary science mission, the Mars Reconnaissance Orbiter will conduct its science investigations using six science instrument payloads. The instruments are: HiRISE, CRISM, MCS, MARCI, CTX and SHARAD. In addition to the instruments, there are two engineering payloads: ONC and Electra. The location of each is shown in figure 3.

The High Resolution Imaging Science Experiment (HiRISE) is multicolor pushbroom imager. The instrument aperture is 50cm and capable of a ground scale factor of 30cm/pixel at 300km altitude. The camera features a 1.15-degree FOV, which provides a swath width of 6km from 300km. The camera focal plane array is comprised of 14 separate Detector Chip Assemblies (DCA) which provide Time Delayed Integration (TDI), pixel binning. Images may be taken in combinations of DCAs and can require up to 28 gigabits.

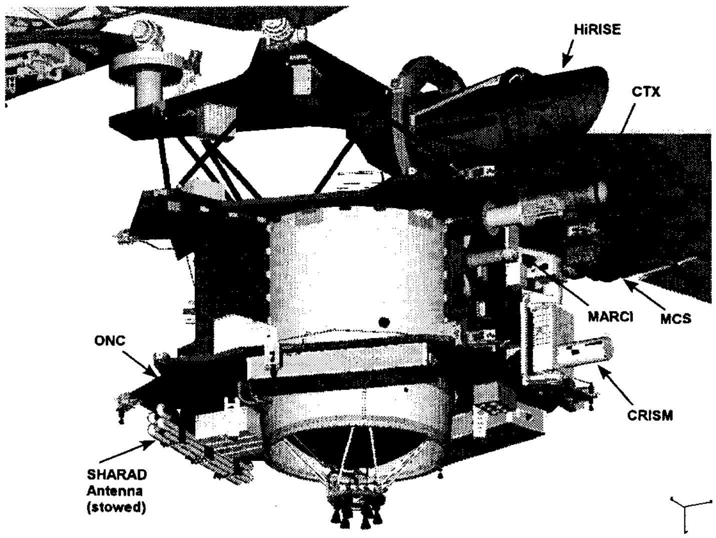

Figure 3 Payload Layout

The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) will provide high-resolution hyperspectral images of areas on Mars in wavelengths from 0.4 to 4.0 micrometers (visible to short-wave infrared) for identifying key mineralogical indicators of water and hydrothermal systems. Such data will be vital for targeting future landed missions. The CRISM telescope has a 10cm aperture with a 2.06-degree field-of-view for its two spectrometers. The entire instrument is mounted on a gimbal, which allows it to follow a specific target on the surface as the orbiter flies overhead. The gimbal can scan a range of ±60 degrees in the along-track direction. CRISM operates with three fundamental observing modes: targeted, atmospheric, and multispectral survey targets are imaged hyperspectrally while the instrument gimbal scans the target area. Atmospheric observations are similar to targeted observations but only measure the center portion of the target and at reduced resolution. Multispectral observations are nadir pointed and use a subset of spectral channels and bin pixels spatially by a factor of 6 or 10.

The Mars Climate Sounder (MCS) explores the structure and aspects of the circulation of the atmosphere. This includes mapping the thermal structure of the atmosphere from the surface to an altitude of 80km, with a vertical resolution of 5km and mapping the seasonal and spatial variability of atmospheric pressure. MCS consists of two identical, 4cm aperture telescopes mounted on an articulating pedestal. This instrument does not require pointing by the spacecraft. The articulation allows the instrument to view the surface of Mars, the limb of Mars, space, and calibration targets. MCS has extremely low data rates and will be operated continuously over the duration of the mission.

The Mars Color Imager, MARCI will take low spatial resolution observations of the atmosphere, provide daily global views of Martian activity, and examine surface features characteristic of the evolution of the Martian climate over time. MARCI is nadir-pointed, has a FOV of 180 degrees, and has selectable resolutions between 1 and 10km per pixel using its five visible bands. Two UV bands provide resolutions better than 10km/pixel.

The Context Camera (CTX) is a facility instrument which will provide panchromatic context imaging for the targeted investigations and will independently address the MRO science goals. CTX typically will be operated simultaneously with the higher-resolution instruments. CTX has a 5.8-degree field-of-view through a 10.8cm aperture, and provides a ground sample distance of 6m/pixel from an altitude of 300km. The 5000-pixel detector produces a swath width of 30km.

The Shallow Radar (SHARAD) will be used to the search for ground ice or water and sub-surface structure. SHARAD is a nadir looking radar sounder with downtrack synthetic aperture capabilities. SHARAD operates at 15-25 MHz and has a vertical resolution of approximately 15 meters. SHARAD can probe as deep as 1km below the surface, but typically will profile structures closer to the surface. SHARAD will be operated primarily at night over selected targets, with occasional polar observations to 60 degrees latitude on the dayside. SHARAD is located on the aft deck of the orbiter and will be deployed once the orbiter is in the primary science orbit.

Electra is a UHF telecommunications package that will be used to provide a command and telemetry, or proximity link as well as collecting Doppler data for navigation to the surface and support Mars approach navigation. Electra will provide near omni-directional coverage of surface assets via its UHF antenna. It will also contribute navigational-related data in the form of one- and two-way Doppler and ranging measurements.

The Optical Navigation camera (ONC) is part of a technology demonstration experiment for future Mars missions. The camera will acquire images of Mars and its moons, Phobos and Deimos. The camera has an aperture of 6cm, a 1.4-degree square field-of-view, and is located on the aft deck of the orbiter.

Mission Operations System Description

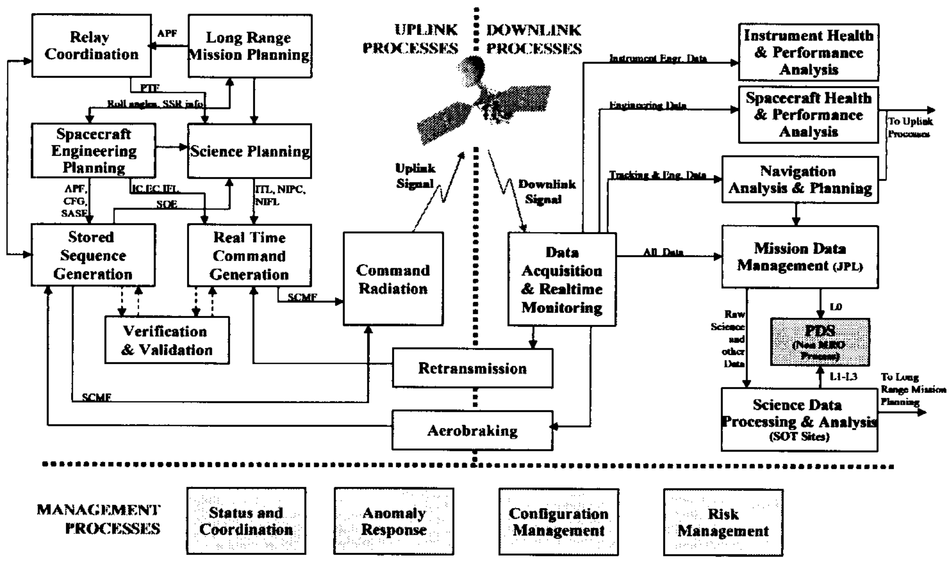

Figure 4 MOS Functional Overview

The MRO Mission Operations System (MOS) is distributed among several institutions and organizations. The MOS inherits key functions, tools and services provided by the Interplanetary Network Directorate (IND-DSMS) and the multi mission teams from the Mission Management Office (MMO). Overall management, coordination, and control of the MOS is provided by the MRO project and its flight team. Spacecraft functions within the flight team are provided by the spacecraft builder. Operations and data processing of the science instruments are provided by the instrument teams at their home organizations combined with data handling, storage, distribution, and operations control functions provided by JPL. A functional overview of the MOS is shown in figure 4.

Launch Vehicle Description

The baseline launch vehicle for the MRO mission is the Lockheed-Martin Atlas V 401. This launch vehicle was selected by NASA-KSC (Kennedy Space Flight Center) via a competitive procurement under the NASA Launch Services (NLS) contract. The Atlas V-401 consists of the Atlas booster with an RD-180 engine, a single engine Centaur upper stage, a 4.2 m payload fairing, and payload interface. Overall, the Atlas has a length of 57.4 meters. Figure 5 shows the Atlas V 401.

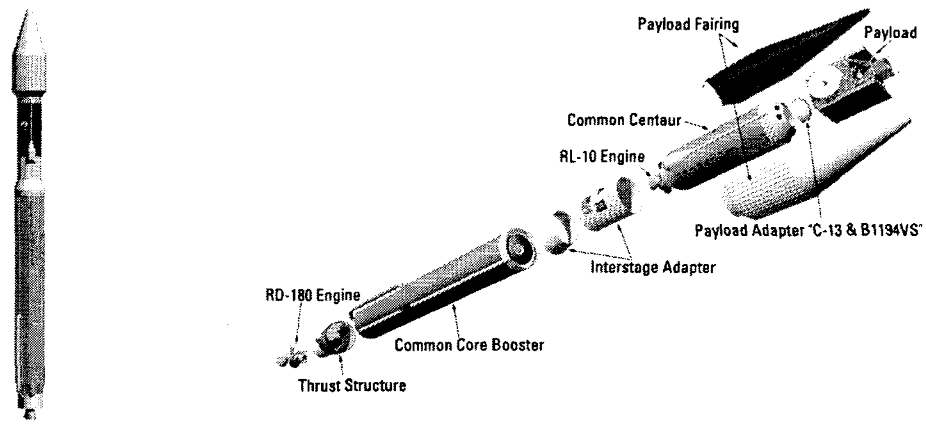

Figure 5 Atlas V 401

MISSION PHASES

Launch

The launch and injection of MRO will occur during the Mars opportunity of August 2005. The launch period will open on August 10th and will have a minimum 21-day duration. The Atlas booster, in combination with the Centaur upper stage, delivers the MRO spacecraft into a targeted parking orbit. After a short coast, a restart of the Centaur upper stage injects MRO onto its interplanetary transfer trajectory. For each day of the launch period, MRO will have a continuous 2 hour window to launch on its Mars bound trajectory. Earth departure conditions will have C3's between 16 and 20 km^2/s^2 and DLA's near 40 deg.

Cruise, Approach and Orbit Insertion

The interplanetary transit time will require about seven months (212 to 197 days depending upon launch date). The cruise phase begins within 3 days after launch when the orbiter is stable and configured for cruise. Key activities during cruise include spacecraft and payload checkout and calibration. These activities along with daily monitoring of orbiter subsystems will be performed in order to fully characterize the performance of the spacecraft and its payload prior to arrival at Mars. In addition, standard navigation activities will be performed during this flight phase with the first and most likely being the largest TCM performed fifteen days after launch. Figure 6 shows a timeline of activities and events for the launch through Mars arrival timeframe.

During the last sixty days of the interplanetary transit, spacecraft and ground activities will become focused on the events necessary for a successful arrival and safe capture at Mars. Navigation techniques will include the use of delta-DOR measurements in the orbit determination. This technique will yield a precise determination of the inbound trajectory with a series of final TCMs used to control the flight path of the spacecraft up to the MOI maneuver.

Also during the approach phase, MRO will perform the Optical Navigation experiment. This involves pointing the optical navigation camera (ONC) at the moons of Mars - Phobos and Deimos, and tracking their motion. By comparing the observed position of the moons to their predicted positions, relative to the background stars, the ground will be able to accurately determine the position of the orbiter.

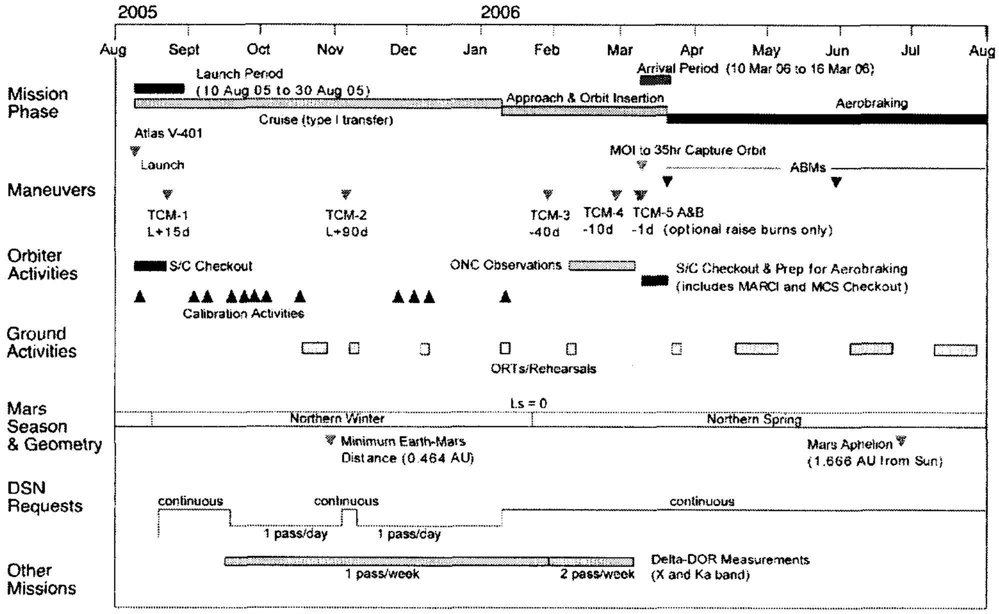

Figure 6 Mission Timeline – Launch, Cruise, Approach and Orbit Insertion, Aerobraking

Upon arrival at Mars on March 10, 2006, the spacecraft will perform its MOI maneuver using its six main engines. MOI will insert the spacecraft into an initial, highly elliptical capture orbit with a period of 35 hours. The DV required to accomplish this critical maneuver is 1015 m/s and will require approximately 25 minutes to complete. For most of the burn, the orbiter will be visible from the DSN stations. The signal will be occulted as the orbiter goes behind Mars. The orbiter will appear again a short time later. The reference MRO capture orbit has a period of 35 hours and a periapsis altitude of 300km. The orientation of the ascending node will be 8:30 PM LMST. The node of the capture orbit node has been selected such that aerobraking operations can be completed prior to the start of the solar conjunction blackout (September 23, 2006).

Aerobraking

One week after MOI, aerobraking operations will commence. During this time period, the orbiter will use aerobraking techniques to supplement its onboard propulsive capability and reduce its orbit period to that necessary for the primary science orbit (PSO). Aerobraking will consist of 4 distinct phases: a walk-in phase, a main phase, a walkout phase and a transition to the PSO. During the walk-in phase, the spacecraft establishes initial contact with the atmosphere as the periapsis altitude of the orbit is slowly lowered. This phase continues until the dynamic pressures and heating rate values required for main phase, or steady state aerobraking, are established. During main phase, large scale orbit period reduction occurs as the orbiter is guided to dynamic pressure limits. Main phase continues until the orbit lifetime of the orbiter reaches 2 days. (Orbit lifetime is defined as the time it takes the apoapsis altitude of the orbit to decay to an altitude of 300km.) When the orbit lifetime of the orbiter reaches 2 days, the aerobraking walkout phase will begin. During the walkout phase, the periapsis altitude of the orbit will be slowly increased as the 2 day orbit lifetime of the orbiter is maintained. Once the orbit of the orbiter reaches an apoapsis altitude of 450km, the orbiter will terminate aerobraking by propulsively raising the periapsis of its orbit out of the atmosphere. Because the PSO has nodal orientation requirements, the aerobraking phase of the MRO mission must proceed in a timely manner and be completed near the time the desired nodal geometry is achieved. Once aerobraking has been terminated, MRO will perform a series of propulsive maneuvers to establish the primary science orbit. The transition time from aerobraking to the primary science orbit will take approximately 10 days. Figure 7 shows the spacecraft in its aerobraking configuration.

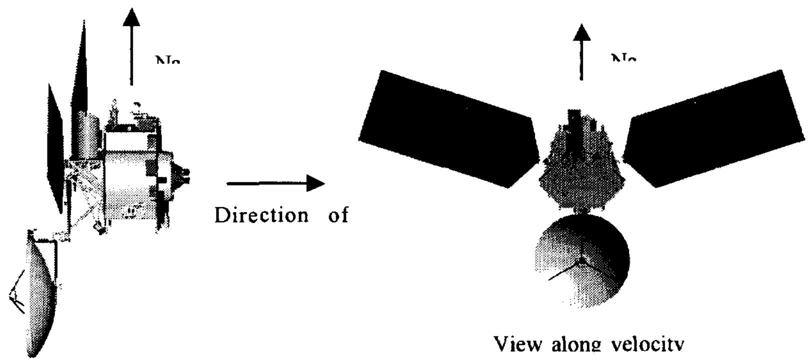

Figure 7 Aerobraking Orientation

When the PSO has been established, the orbiter and its payload will be configured and calibrated and made ready for science data acquisition in the primary science phase. As part of these activities, the orbiter orientation will be changed to its nadir tracking mode, the SHARAD antenna and CRISM cover will be deployed, and several calibrations and initial observations will be performed. Figure 8 shows a timeline of events for the transition activities.

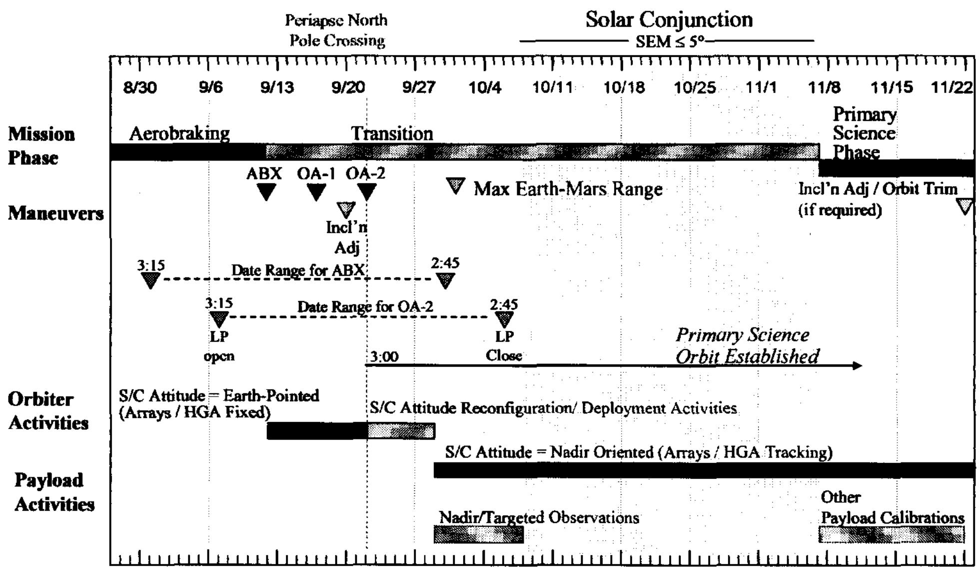

Figure 8 Transition Activity Timeline

Primary Science

The primary science phase is the period of concentrated science return for the mission. It begins when the orbiter is delivered into the primary science orbit and declared ready for the collection of science data. This occurs after the end of solar conjunction in November 2006 and ends with the start of solar conjunction in November 2008. This inter-conjunction interval of 740 days allows a margin of 8% above the minimum 687 days (one Mars year) for the primary science phase and also allows proper closure of the seasonal cycle observations by MRO.

Toward the end of the primary science phase, other Mars missions launched in the 2007 opportunity will begin to arrive. Phoenix, the first of the Mars Program's Scout missions has been selected to launch in the 2007 Mars opportunity. Phoenix is a lander mission that will collect and analyze soil samples and will arrive in late May 2008. It will need science imaging support for site characterization and selection and Electra UHF relay support for its Entry Descent and Landing activities and for its science data return. A timeline of activities in the primary science phase is shown in figure 9.

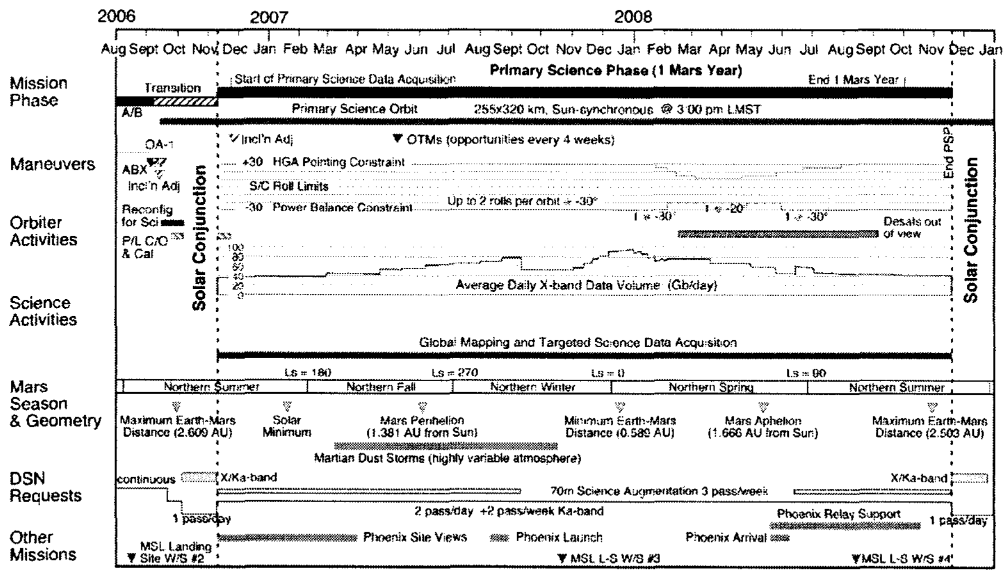

Figure 9 Mission Timeline - Primary Science

During the primary science phase, the orbiter configuration will be such that the instruments, mounted on the orbiter +Z face (or Nadir deck), will be pointed nadir (i.e. local normal to the reference ellipsoid), and the HGA and solar arrays will be tracking the Earth and the Sun, respectively. From the perspective of the orbiter, the +X direction is in the direction of the ground velocity vector. Compensating for planetary ground motion requires a slight yaw motion (around +Z) of about ±4 degrees over the course of one orbit.

Science data collection in this attitude is useful for observing horizon-to-horizon, atmospheric limbs, and surface features that lay along the spacecraft ground track. In addition to this baseline nadir science data collection mode, the spacecraft has the capability to perform limited off-nadir targeting. During targeted observations and special calibrations, the spacecraft will roll in the cross-track direction (around +X). Figure 10 illustrates the orbiter science configuration as viewed from the direction of the Sun. The spacecraft is designed, from a power and thermal perspective, to accommodate roll angle slews off of nadir up to ±30 degrees. To simplify Mission Operations, it is desired to maintain high rate communications during these off-nadir targeting sessions. This continuous communication goal forces the maximum roll angle to be less than 30 degrees for a limited portion of the primary science phase due to HGA gimbal singularity limitations. Additionally, power / energy balance constraints may also limit the maximum roll angle for additional limited portions of the primary science phase.

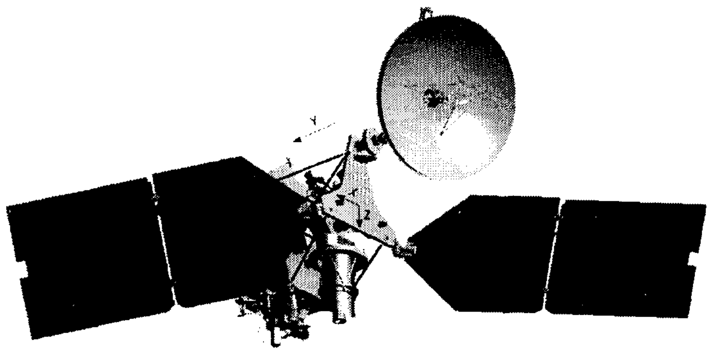

Figure 10 MRO Orbiter – Science Configuration

The primary science orbit (PSO) has been designed to satisfy the science requirements of the mission. This orbit has the following characteristics:

- a Sun-synchronous ascending node at 3 P.M. local mean solar time (LMST) -- daylight equatorial crossing (near polar inclination of 92.7 deg);
- an eccentricity and argument of periapsis that results in a low altitude "frozen" orbit (periapsis altitude of 255km, apoapsis altitude of 320km, and an argument of periapsis of 270 deg); and
- a semi-major axis that will produce a 17-day (short term) groundtrack repeat cycle (semi-major axis of 3775km).

Because of the 3:00 pm LMST orbit orientation, the MRO spacecraft will experience a solar eclipse on each orbit. Additionally, on almost every orbit, the spacecraft will experience an Earth occultation. The Earth occultations cause the orbiter to lose contact with the DSN. This has a noticeable effect on the downlink data volume capability of the mission.

To simplify the complex observation geometry associated with other types of low altitude orbits at Mars, the MRO spacecraft will be put into a "frozen" orbit. The "frozen" orbit condition results in a periapsis that remains stationary over the South Pole of Mars. With the periapsis location fixed, a 65-70km range between the periapsis and apoapsis altitudes above the surface results naturally due to the Martian gravity field. Variations in the spacecraft altitude above the Martian surface at specific latitudes are limited to just a few kilometers. It should be noted that the periapsis of the MRO orbit is 115km lower than that of current spacecraft (Mars Global Surveyor and Mars Odyssey) orbiting at Mars.

Because of the different observations modes (global mapping and profiling, regional survey, and globally distributed targeting) of the science suite, the PSO has been designed to produce two groundtrack repeat cycles. First, there is a long-term repeat cycle that provides uniform, global coverage of Mars with a fine grid of less than 5km at the equator. Except for atmospheric perturbations, this is the exact repeat of the groundtrack that will occur after 4602 revs [359 days (349 sols)]. Second, there is a short-term repeat cycle, or targeting cycle, that will occur every 211 revs [17 days (16.5 sols)]. The targeting cycle is not an exact repeat; it has a 31 km westward walk relative to any selected reference node. This short term repeat cycle allows for quick global access to the planet and repeated targeting (data take) opportunities. Due principally to atmospheric perturbations, the planned groundtrack repeat cycles may not be easily achievable. Regular orbit trim maneuvers are expected to be necessary in order to control the groundtrack repeat patterns. Because of the potential groundtrack control issues and as a way to enhance the targeting aspect of the mission, the spacecraft has been designed to roll and take data ±30 degrees crosstrack of nadir. For the altitude range of the PSO this is equivalent to approximately 165km on the surface. Because of impacts to global mapping investigations, targeted observations with roll angles less than 10 degrees will be preferred.

Relay

The relay phase begins upon completion of the primary science phase in December 2008 and continues until the end of the mission at the end of calendar year 2010. During this phase, the MRO orbiter will support the Mars Exploration Program by providing navigation and relay communications support to various Mars landers and orbiters through its Electra payload. NASA may approve, as resources and on-orbit capability permit, continuation of science observations beyond the Primary Science Phase until end of the Relay Phase (also End of Mission). The Mars Science Laboratory (MSL) is proposed for the 2009 Mars opportunity. Figure 11 shows the key timeline events, including key MSL milestones, that are relevant to the MRO Relay phase.

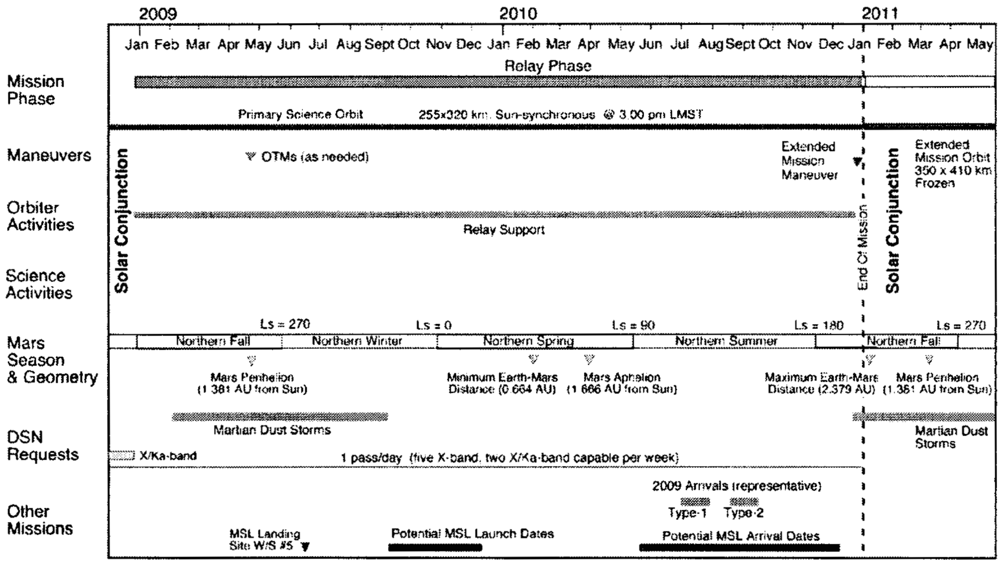

Figure 11 MRO Mission Timeline - Relay

During the relay phase, the orbiter will continue to operate from the Primary Science Orbit (255 x 320 km, 3:00 pm LMST) in a nadir down configuration. The orbiter is capable of slewing to point the antenna at the surface asset, in the same way as during a targeted science observation (i.e., +/- 30 degree roll from nadir via the on-board ITL)). MRO provides the capability to communicate with only one surface asset at a time. MRO has a ΔV allocation of 20 m/s to perform in-plane phasing maneuvers to optimize viewing geometry of in-coming mission critical events such as EDL or orbit insertion. These maneuvers change the position of the orbiter (true anomaly) within its orbit. No ΔV has been allocated for orbit plane or altitude changes.

MRO's high inclination orbit allows for relay access to any point on Mars. Locations near the poles will experience frequent contacts with minimal gaps, while locations near the equator experience less frequent contacts with greater gaps. A gap is the duration of time between geometric contact opportunities (e.g., when MRO is greater than 20 degrees above the horizon as viewed by the surface asset). Due to the elliptical nature of MRO's orbit and the oblate shape of Mars, pass duration varies slightly with latitude. Pass duration is the time when MRO is greater than 20 degrees above the horizon with respect to the landed asset. In general, pass durations are about 4 1/2 to 5 minutes in the equatorial latitudes.

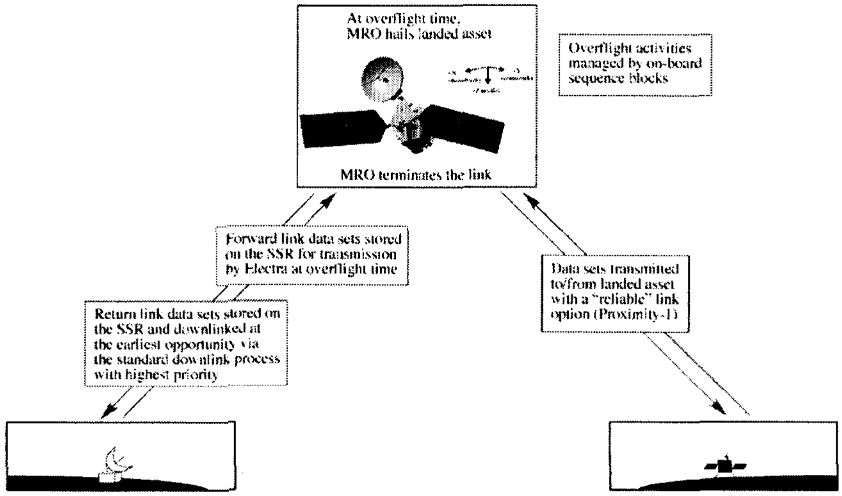

Figure 12 Typical Activities during a Relay Session

All relay sessions between MRO and a surface asset will be initiated by MRO. At the time of the overflight, MRO will hail the surface asset. Once the surface asset has responded, the session will begin. All information can be transferred via a reliable link (Proximity-1 protocol). Once all the data has been transferred, or the overflight is about to end, MRO will terminate the link. Figure 12 shows the activities performed during a typical relay session. The Electra payload will be able to send up to 30 Mbits/day to a surface asset (forward link). MRO can return up to five Gbits/day of surface asset telemetry (return link). Available relay rates are: 8, 16, 32, 64, 128, 256, 512, 1024, and 2048 kbps.

MRO and its Electra payload can provide navigation services to other Mars missions in several ways. Electra can collect and downlink 1 and 2-way Doppler data while in contact with another UHF transmitter or transceiver. The MRO telecom subsystem can send an X-band signal through the HGA to another spacecraft that has an X-band equipped Electra.

The end of the MRO mission occurs at the completion of the Relay phase and is defined as December 31, 2010. At that time, if it hasn't already done so, MRO will perform a maneuver that will raise the orbit altitude. The new orbit will be approximately 20 km lower than that of MGS, and its purpose is to extend MRO's orbital lifetime. Enough ACS propellant has been allocated to last through 2015 to support future Mars missions.

DATA ACQUISITION STRATEGY

The science investigations are functionally divided into daily global mapping and profiling, regional survey, and globally distributed targeting investigations. The global mapping instruments require nadir pointing, low data rate, and continuous or near-continuous operations. The targeted and survey investigations use high data rate instruments and will require precise targeting in along-track timing and/or cross-track pointing for short duration observations over selected portions of the surface. All instruments can take data simultaneously. Along with the MRO investigations, the Mars Exploration Program (MEP) expects to make use of the high resolution imaging capabilities of the orbiter to characterize and certify hundreds of sites on Mars that could be used as landing sites for future missions.

The science data acquisition strategy is predicated on the Primary Science Orbit characteristics, the objectives of the selected science investigations, and the available orbiter resources and capabilities.

Investigation priorities, targeted observations and data allocations will be coordinated in advance by the science teams, culminating in meetings every four weeks of the Target Acquisition Group or TAG, which includes membership from the PSG and representatives of the Mars Exploration Program. A view of the observation planning and sequencing process is shown in figure 13.

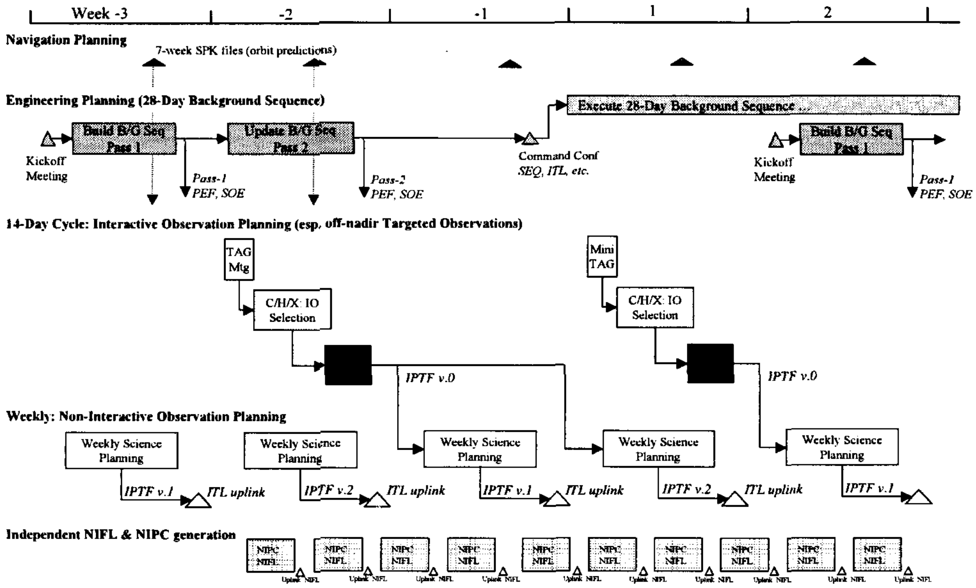

Figure 13 Science Sequence Planning Process

There are two fundamental types of science observations: Non-Interactive Observations and Interactive Observations. Non-interactive observations do not require the spacecraft or other instruments to change modes or support them. Investigation teams plan their non-interactive observations independently of other investigations. Non-interactive observations can be made anytime the spacecraft is nadir pointed unless there are interactive observations that are in conflict. Non-interactive nadir observations are commanded via non-interactive payload commands (NIPC) and sent independently of orbiter sequences up to a few hours or days before the observation is made. Non-interactive observations could be high or low resolution images, survey observations, or global mapping observations.

Interactive observations are those that require the spacecraft or another instrument to change its mode. Examples of this include off-nadir targeting (spacecraft rolls), observations that require suspension of MCS or solar array motion (high stability observations), and nadir observations that exclude slews while observing. Interactive observations are always planned and coordinated by the TAG.and with the orbiter background sequencing process. Integrated Target Load, (ITL) files are generated that specify the Mars relative pointing parameters. This allows pointing software on the orbiter to calculate the appropriate pointing direction and update the time of the observation based on the most recently uploaded ephemeris files. Updates to the instrument specific observation parameters can be made via NIPC days or up to hours prior to the observation

The number of off-nadir targets per day is constrained to 20 per day or 2 per orbit for planning purposes. The required number of interactive off-nadir targets during the primary science phase is 2000 (1000 for single instrument observations and 1000 for multiple instrument observations). The expected capability of the orbiter and MOS, however, have led the investigation teams to plan to acquire on the order of 6000 interactive images during the primary science phase.

DATA RETURN STRATEGY

Data acquired by the MRO science instruments will be stored on the Solid State Recorder (SSR). The orbiter Command and Data Handling subsystem will prepare and/or process the science data and store it as downlink telemetry frames in temporary SSR buffers queued for downlink via the Small Deep Space Transponder (SDST). Data will be acquired based on data volume allocations that match the X-band downlink data volume capability of the orbiter-DSN link. All acquired data will be transmitted to the DSN. For each 4-week period during the mission, the TAG will provide data allocations based on the estimated data volumes associated with the scheduled DSN tracking for the period.

SSR management will entail allocation of partition space such that all daily data volume allocations will be available for science observations. Each instrument (except MCS) and Electra will have partitioned data allocations for raw instrument data. The SSR will have other partitions for framed telemetry data queued for downlink by priority type. The partitions are sized to allow all instruments to collect their allocated data volumes on a daily basis. The SSR can be repartitioned as often as monthly, however, it is expected that repartitioning will be needed only a few times during the primary science phase. Repartitioning will likely cause all or most observing to be suspended for about a day to avoid loss of stored data.

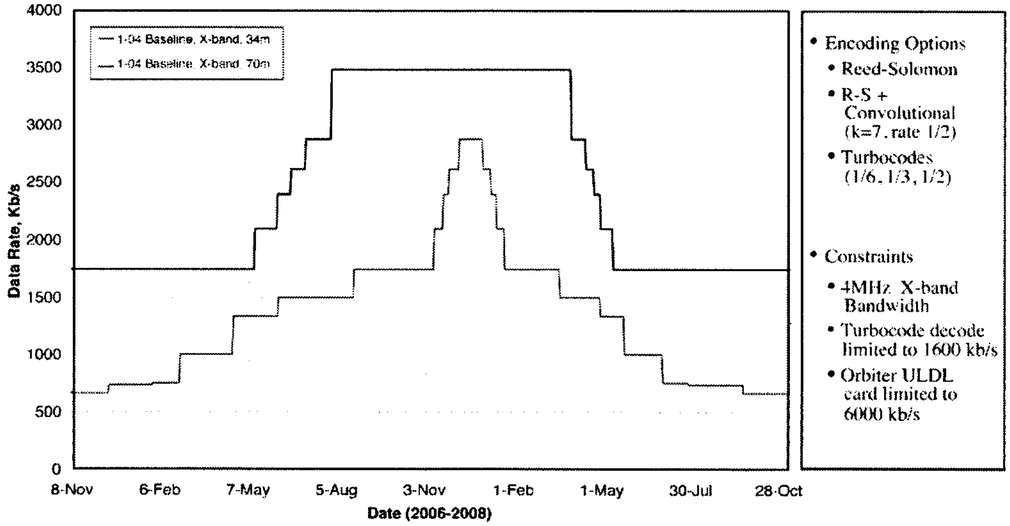

Figure 14 Daily Data Rates in the Primary Science Phase

The MRO spacecraft will be designed to provide at least 500 kbps at maximum range (2.61 AU) to a 34m BWG station using Turbo 1/3 encoding. At closer ranges the signal strength will be greater and a higher data rate will be possible. MRO will also have a variety of coding schemes available to maximize the rate capability at a particular range. The orbiter and the DSN have several constraints on the symbol rates, data rates, and signal bandwidth used at a given time. Figure 14 shows the daily data rates for every day of the primary science phase. The rates result from the best combination of coding scheme, link strength and constraints.

In addition to the baseline two 8-hour tracks per day during the science phase, 70m coverage and Ka-band coverage will be requested. 70m passes will be used to augment the baseline plan, allowing for additional data return during periods where the Earth-Mars range is near its maximum. The 70m passes will be scheduled three times per week from November 2005 to June 2007 and from February 2008 to November 2008. Ka-Band capable 34m-BWG antennas will be requested twice per week for the entire primary science phase as part of a Ka-band operational demonstration experiment.

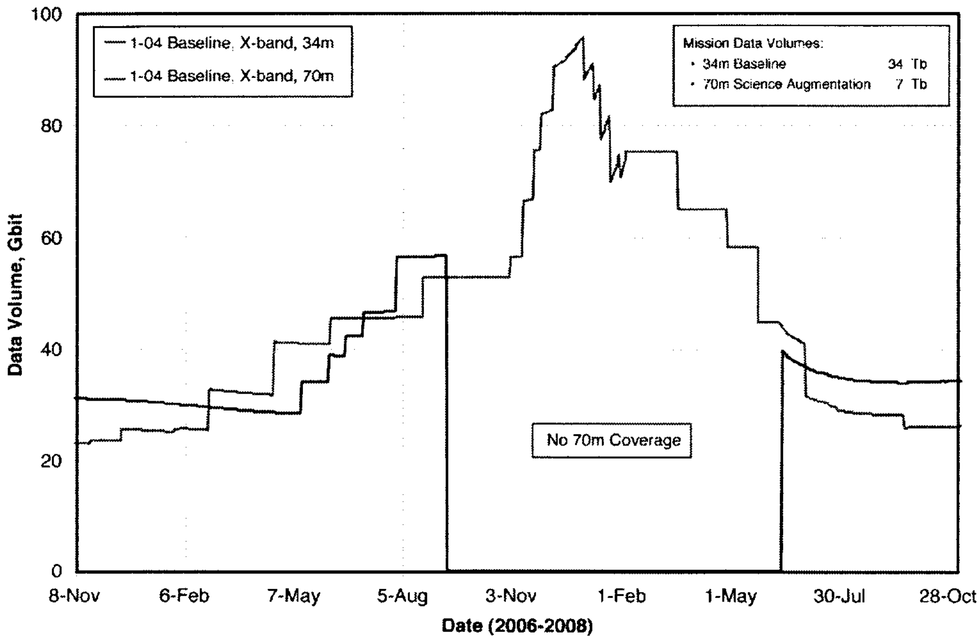

Figure 15 Daily Data Volumes in the Primary Science Phase

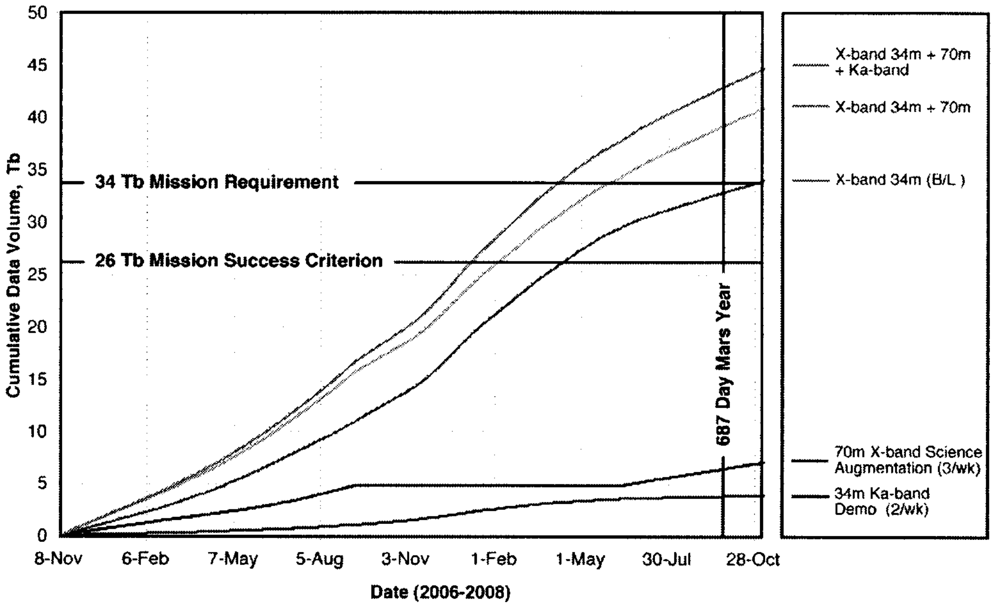

Figure 16 Cumulative Data Volumes in the Primary Science Phase

The mission requirement for total data volume returned is 34 Tbits. The minimum daily data volume is about 20 Gbits per day. Data Volumes from MRO are calculated from the data rate at a particular time and from the amount of time available for downlink. The time available for downlink is a function of orbit period, occultation duration, navigation uncertainty, lockup time assumptions, tracking time assumptions, and the duration of orbiter activities that prevent downlink (e.g., HGA off-pointing). Data rate and downlink duration vary day to day. Figure 15 shows the baseline daily data volume and figure 16 shows the cumulative data volume for the Primary Science Phase.

The objectives of the Ka-band Operational Demonstration Experiment are to enable DSMS to design and implement operational Ka-band capabilities. The experiment will demonstrate Ka-band operational feasibility and enhanced telemetry data return, test the performance of a Ka-band deep-space telecommunications link over an extended period of time, and assess effects on the Ka-band performance of atmosphere, wind loading, charged-particles, antenna mechanical pointing and operational impacts. Some planned activities will make use of a priori information such as weather forecasts to set optimum data rates, while others will exercise multiple data rates during a pass to improve total data volume. Several activities are planned to stress test Ka-band links to force bit errors in order to validate frame or bit error performance models. The navigation component of the experiment evaluates the performance of the Doppler, range and Delta-DOR data types on a pass-by-pass basis.

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